

CONE BEAM CT FOR DENTAL AND MAXILLOFACIAL IMAGING: DOSE MATTERS

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The widespread use of cone-beam CT (CBCT) in dentistry has led to increasing concern regarding justification and optimisation of CBCT exposures. When used as a substitute to multidetector CT (MDCT), CBCT can lead to significant dose reduction; however, low-dose protocols of current-generation MDCTs show that there is an overlap between CBCT and MDCT doses. More importantly, although the 3D information provided by CBCT can often lead to improved diagnosis and treatment compared with 2D radiographs, a routine or excessive use of CBCT would lead to a substantial increase of the collective patient dose. The potential use of CBCT for paediatric patients (e.g. developmental disorders, trauma and orthodontic treatment planning) further increases concern regarding its proper application. This paper provides an overview of justification and optimisation issues in dental and maxillofacial CBCT. The radiation dose in CBCT will be briefly reviewed. The European Commission's Evidence Based Guidelines prepared by the SEDENTEXCT Project Consortium will be summarised, and (in)appropriate use of CBCT will be illustrated for various dental applications.

CONE-BEAM CT: A PARADIGM SHIFT IN DENTAL IMAGING

Cone-beam CT (CBCT) was introduced into dental imaging more than 15 y ago. It has proved to be a useful modality for imaging of the hard tissues and air cavities of the dental and ear–nose–throat areas. The introduction of CBCT has dramatically altered the perception on the use of three-dimensional (3D) imaging for dental applications. Whereas the use of CT imaging was limited in dentistry before, CBCT has now become an integral part of the diagnostic toolset for several dental specialties. It is currently applied for several purposes, such as implant planning, endodontics, orthodontics and maxillofacial surgery⁽¹⁾. About 50 CBCT models are currently on the market, exhibiting a wide range in selectable exposure parameters [kVp, mAs, field of view (FOV) size, etc.].

The widespread use of CBCT can be attributed to several factors. A crucial advantage of CBCT, albeit not related to radiological protection, is accessibility. The low cost, small size and limited medico-legal requirements of CBCT allow it to be placed in dental practices and clinics that cannot accommodate a multidetector CT (MDCT). Several benefits are associated with this, such as reduced treatment time and increased patient comfort.

Other advantages relate to the imaging performance of CBCT compared with two-dimensional (2D) imaging modalities (e.g. intra-oral and panoramic radiography) and MDCT. The ability to acquire a three-dimensional image can result in superior diagnostic capabilities and a more accurate treatment planning compared with 2D radiographs. Compared with MDCT, the increased sharpness of CBCT allows

for the visualisation of small structures in the dental area (e.g. root lesions). Both of these considerations justify the use of CBCT for a subset of dental patients but proper nuance is needed. The added value of 3D imaging, at least when used routinely, is considered questionable for certain dental applications and lacks conclusive evidence⁽¹⁾. Regarding image sharpness compared with MDCT, it has been shown that a wide range in image quality exists in CBCT, with some CBCTs demonstrating a lower resolution than that of MDCT⁽²⁾.

In addition, several misconceptions about CBCT imaging are commonly seen. It is often described as a 'low-dose' modality, which is falsely attributed to the fact that it requires only a single rotation (or less) around the scanned object. In fact, similar to the range in image quality, a wide range in doses is seen in CBCT, overlapping with doses from MDCT and panoramic radiography^(3–8). Also, it is typically deemed 'fast', although the scan time of a CBCT significantly exceeds that of current-generation MDCTs and, in many cases, that of a panoramic radiograph.

While it is indisputable that CBCT has a rightful place in dental imaging and has the ability to improve patient treatment in many cases, it is important to temper the overall optimism and to keep stressing the importance of radiological protection issues associated with the use of this modality. The following section will go deeper into the topic of radiation dose in CBCT. A summary of the European Commission's Evidence Based Guidelines prepared by the SEDENTEXCT Project Consortium will be given⁽¹⁾. Next, a few examples of proper and improper use of CBCT will be demonstrated with the aid of various guidelines and position statements, and future prospects for CBCT imaging will be discussed.

RADIATION DOSE IN CBCT

Patient dose for dental CBCT has been extensively reported^(3–7). The variety of dosimetric information available, involving different CBCT models, dose metrics and methodologies, complicates a comparison between studies and inhibits the drawing of general conclusions. However, a few general considerations can be made regarding doses and risks from CBCT, and how these relate to those from alternative imaging modalities.

An obvious, yet important, finding is that CBCT shows a wide dose range, as can be expected from the variable exposure parameters used by different models. Small FOVs can be used to scan the area of a single tooth, whereas certain large FOVs cover most of the patient's head. Clinical kVp values range between 70 and 120 kV, whereas mAs values range more than 20-fold but are generally between 25 and 150 mAs.

Measuring effective doses for clinical dental protocols of 14 CBCT models, Pauwels *et al.* showed a 19-fold dose range⁽⁴⁾, whereas Ludlow *et al.* measured a 16-fold range for 8 models⁽³⁾. Rottke *et al.* used a different approach, measuring doses for minimum and maximum exposure parameters provided by 10 CBCT models, finding a 23-fold dose range⁽⁷⁾. It should be noted that CBCT models often offer a wider range of exposure parameters than those used for clinical dental imaging, with lower exposure settings only being used during quality control and higher exposures being applied for non-dental (e.g. ear) applications.

Corresponding with the wide range in effective dose, doses to individual organs show large variations due to varying exposure settings and FOV positions. Absorbed organ doses of 0.03–10.0 mGy have been reported for the thyroid gland, 0.02–9.3 mGy for the brain and 0.03–16.7 mGy for the eye lens^(3–6).

Comparing CBCT with those of other modalities, some overlap is noticeable. CBCT doses of >500 μ Sv have been reported^(3, 6), whereas low-dose CT protocols of 180 μ Sv with adequate image quality for implant and surgery planning have been proposed in 2005 by Loubele *et al.*⁽⁸⁾ Due to the decreased use of MDCT for dental applications, recent dose reports on current-generation models are not available; it can be expected that innovations in detector technology, image reconstruction and other aspects allow for MDCT to reach lower doses than those reported in older literature.

Comparing CBCT with 2D modalities, while there is a clear difference in dose with intra-oral and cephalometric radiography, some overlap can be seen between CBCT and panoramic radiography⁽⁹⁾. However, two additional considerations should be made. While small-FOV CBCTs are able to reach very low doses, they cannot be considered as true alternatives for panoramic radiographs, which cover

the entire dentomaxillofacial area. In addition, low-dose protocols from modern CBCT equipment may result in doses similar to the high end of the range for panoramic radiographs reported in literature, but modern panoramic equipment results in patient doses that medium- or large-FOV CBCTs cannot possibly reach.

Most dosimetric studies on CBCT use a similar methodology, by estimating the effective dose through point measurements in an anthropomorphic phantom representing an average adult male. It is important to remark that dose ranges and dose differences measured using this approach cover only a small portion of the actual dose and risk ranges for patients. As noted by Martin, there can be a large discrepancy between phantom and patient doses, due to varying patient anatomy (e.g. mass, size and location of organs)⁽¹⁰⁾. The use of paediatric phantoms has illustrated that higher doses are seen for smaller patients when exposure factors are not modified^(11, 12). In addition, risks from radiation exposures are determined not only by dose but other patient-specific factors such as age and gender. Therefore, whereas differences in radiation doses mentioned earlier can often be considered small, the actual risk can vary severely, particularly for paediatric patients.

SEDENTEXCT GUIDELINES

The SEDENTEXCT (Safety and Efficacy of a New and Emerging Dental X-ray Modality) project was a multicentric collaboration, funded by the European Atomic Energy Community's Seventh Framework Programme. Based on an extensive review of literature and aided by experimental work on radiation dose, image quality and diagnostic efficacy performed within the project, evidence-based guidelines were compiled by the SEDENTEXCT Consortium. These guidelines are published as Radiation Protection Publication 172 of the European Commission⁽¹⁾.

Various aspects of radiological protection in dental CBCT were covered in these guidelines, such as justification, optimisation of exposures, user training and quality assurance. Apart from a detailed description of guidelines related to these topics with varying evidence levels, twenty 'Basic Principles' were defined using a consensus-based approach, which involved members of the European Academy of Dento-Maxillo-Facial Radiology (Table 1).

Several Basic Principles are interpretations of the general radiological principles of justification and optimisation of exposures. Justification is a crucial aspect, as the excessive use of CBCT in dentistry would increase the collective dose considerably. The use of CBCT in dentistry can only be considered as justified if a patient history and clinical information are available, if it is expected to add new information

Table 1. 'Basic Principles' on the use of dental CBCT⁽¹⁾.

1. CBCT examinations must not be carried out unless a history and clinical examination have been performed
2. CBCT examinations must be justified for each patient to demonstrate that the benefits outweigh the risks
3. CBCT examinations should potentially add new information to aid the patient's management
4. CBCT should not be repeated 'routinely' on a patient without a new risk/benefit assessment having been performed
5. When accepting referrals from other dentists for CBCT examinations, the referring dentist must supply sufficient clinical information (results of a history and examination) to allow the CBCT practitioner to perform the justification process
6. CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional (traditional) radiography
7. CBCT images must undergo a thorough clinical evaluation ('radiological report') of the entire image data set
8. Where it is likely that evaluation of soft tissues will be required as part of the patient's radiological assessment, the appropriate imaging should be conventional medical CT or MR, rather than CBCT
9. CBCT equipment should offer a choice of volume sizes, and examinations must use the smallest that is compatible with the clinical situation if this provides less radiation dose to the patient
10. Where CBCT equipment offers a choice of resolution, the resolution compatible with adequate diagnosis and the lowest achievable dose should be used
11. A quality assurance programme must be established and implemented for each CBCT facility, including equipment, techniques and quality control procedures
12. Aids to accurate positioning (light beam markers) must always be used
13. All new installations of CBCT equipment should undergo a critical examination and detailed acceptance tests before use to ensure that radiation protection for staff, members of the public and patient are optimal
14. CBCT equipment should undergo regular routine tests to ensure that radiation protection, for both practice/facility users and patients, has not significantly deteriorated
15. For staff protection from CBCT equipment, the guidelines detailed in Section 6 of the European Commission document 'Radiation Protection 136. European Guidelines on Radiation Protection in Dental Radiology' should be followed
16. All those involved with CBCT must have received adequate theoretical and practical training for the purpose of radiological practices and relevant competence in radiation protection
17. Continuing education and training after qualification are required, particularly when new CBCT equipment or techniques are adopted
18. Dentists responsible for CBCT facilities who have not previously received 'adequate theoretical and practical training' should undergo a period of additional theoretical and practical training that has been validated by an academic institution (University or equivalent). Where national specialist qualifications in DMFR exist, the design and delivery of CBCT training programmes should involve a DMF Radiologist
19. For dento-alveolar CBCT images of the teeth, their supporting structures, the mandible and the maxilla up to the floor of the nose (e.g. 8×8 cm or smaller fields of view), clinical evaluation ('radiological report') should be made by a specially trained DMF Radiologist or, where this is impracticable, an adequately trained general dental practitioner
20. For non-dento-alveolar small fields of view (e.g. temporal bone) and all craniofacial CBCT images (fields of view extending beyond the teeth, their supporting structures, the mandible, including the TMJ, and the maxilla up to the floor of the nose), clinical evaluation ('radiological report') should be made by a specially trained DMF Radiologist or by a Clinical Radiologist (Medical Radiologist)

and if 2D radiographs do not (or are not expected to) answer the diagnostic question. Repeated CBCT examination should be avoided unless each examination can be individually justified. In addition, CBCT should not be used if soft tissue assessment is required, since only MDCT or magnetic resonance imaging provides the contrast resolution required for soft tissue imaging.

An important optimisation principle in dental CBCT relates to the choice of the appropriate volume size for each examination. In many cases, the region of interest is known exactly before scanning; in other cases, the required FOV is revealed after acquisition of a frontal and/or lateral scout image. The smallest available FOV size should always be chosen, as this could greatly reduce the patient dose. The choice between high- and low-dose settings should be made according to the general principle of optimisation, ensuring adequate image quality for diagnosis at the

lowest achievable dose. For low-dose protocols, while conclusive evidence is lacking, recent research has indicated that an mAs reduction could be preferred over a kVp reduction, as the increase in noise is smaller for the former at the same dose level⁽¹³⁾.

Since CBCT images often contain structures that are not part of the diagnostic region of interest (although this should be limited as much as possible through FOV reduction), the EC guidelines also state that the entire image should be examined and reported, not just the region of interest. Depending on the scanned region, the involvement of an oral or medical radiologist can be warranted.

(IM)PROPER USE OF CBCT

The (im)proper use of CBCT will be illustrated for different dental applications. Although it is often

debatable whether or not CBCT examinations are appropriate, a few observations can be made.

Implant planning

The most common application of CBCT in dentistry is for the preoperative planning of implants. Understandably, it is considered the application for which the value of 3D imaging is clearest; the American Academy of Oral and Maxillofacial Radiology (AAOMR) and European Association of Osseointegration (EAO) already acknowledged the benefit of cross-sectional imaging for implant patients in 2000 and 2002, respectively^(1, 14). CBCT allows for the assessment of bone dimensions and nearby anatomy at potential implant sites, enabling the practitioner to decide on the proper size and angulation of implants and to plan the preparation and (if needed) augmentation of the implant site. Still, an important remark pertaining to the use of CBCT for implant patients is that, despite the wide use and availability of CBCT, there is still a need for more evidence pertaining to its added value for straightforward implant cases.

Both the AAOMR and EAO published an updated position statement on the use of radiography for implants, with a focus on CBCT, in 2012^(14, 15). The AAOMR recommended that initial assessment of dental implant patients should be done using panoramic radiography supplemented by intra-oral radiography, avoiding the use of CBCT for initial examination⁽¹⁴⁾. However, they propose that the examination of a potential implant site should be done using cross-sectional imaging, with CBCT being the modality of choice. Conversely, the EAO stated that no cross-sectional imaging is required if clinical evaluation reveals adequate bone width and 2D radiographs show bone height and relevant anatomical structures appropriately⁽¹⁵⁾, whereas the SEDENTEXCT guidelines emphasise that 'the primary question for clinicians is whether or not cross-sectional imaging is required for implant planning'⁽¹⁾. The EAO and AAOMR are in agreement that particular consideration of CBCT should be made when augmentation or other preparations of the implant site are required, both before and after these procedures are performed.

Regarding post-operative imaging, the application of CBCT is limited due to the induction of metal artefacts by implants and an inferior resolution to intra-oral radiography. The AAOMR and EAO recommended the use of intra-oral or panoramic radiography post-operatively, in the absence of signs or symptoms. Cross-sectional imaging can be considered if implant mobility, nerve damage or sinus-related infection is present. For periodic follow-up, CBCT should not be used unless in cases of implant failure requiring surgical removal.

It is crucial to remark that these referral criteria apply only under the strict condition of dose optimisation. When acquiring a CBCT image on an implant patient, it is important to limit the FOV to the implant site, including any adjacent areas that require evaluation (e.g. maxillary sinus). In addition, the required image quality for this application is relatively limited (e.g. bone dimensional assessment, general evaluation of bone quality and visualisation of adjacent structures), implying that low-dose protocols would generally suffice.

Endodontic evaluation

The European Society of Endodontology (ESE) has recently published a brief position statement on the use of CBCT in endodontics⁽¹⁶⁾, whereas the American Association of Endodontists (AAE) in collaboration with the AAOMR published a position paper in 2011⁽¹⁷⁾. Both publications show considerable agreement with the SEDENTEXCT guidelines⁽¹⁾. Their main recommendation is the consistent use of small FOVs for endodontic purposes, as these are typically confined to a single tooth and its adjacent area. Another benefit of small FOVs is that they can be reconstructed at smaller voxel sizes than large FOVs due to computational and storage limitations of the current technology; the increased spatial resolution which is, up to a certain limit, associated with smaller voxels can be of benefit for several endodontic applications.

The ESE recommended that CBCT may be considered for the following endodontic applications, should 2D radiography not suffice: periapical pathosis with contradictory signs/symptoms, non-odontogenic causes of pathosis, complex dento-alveolar trauma (e.g. horizontal root fractures), complex root canal systems prior to endodontic treatment, complications of endodontic treatments (e.g. perforations), root resorption amenable to treatment and pretreatment assessment of complex periradicular surgery⁽¹⁶⁾. Similarly, the AAE-AAOMR have stated that limited-FOV, high-resolution CBCT can be applied to complex endodontic cases⁽¹⁷⁾. The use of intra-operative and post-operative CBCT for endodontic purposes is inappropriate. The former is not only inconvenient for both patient and dentist but has little or no benefit compared with intra-oral radiography, except for certain intra-operative complications. The latter may only be advised if symptoms remain or complications arise.

Orthodontics

The use of CBCT in orthodontics is of particular concern due to the younger age (and associated higher cancer risk) of patients undergoing orthodontic treatment. In addition, patient gender is of

importance, due to the higher radiation risk for females at younger ages and the earlier development of dentition in females. A position statement by the AAOMR provided general recommendations on justification and optimisation of CBCT before, during and after treatment for various types of orthodontic patients⁽¹⁸⁾.

Selection criteria from the AAOMR indicate that CBCT is likely indicated during (1) pretreatment evaluation of dental structure/position anomalies (e.g. supernumerary teeth, resorption and impaction), using a small FOV and (2) presurgical asymmetry evaluation (e.g. mandibular or midline deviation), using a medium or large FOV. The SEDENTEXCT guidelines agree on the potential of CBCT for localised applications but reject the routine use of large-FOV CBCT for orthodontic purposes, highlighting the need for more research demonstrating its benefit to patient outcome⁽¹⁾. For other applications, such as imaging of the temporomandibular joint (e.g. hyper/hypoplasia) and facial discrepancies (e.g. malocclusions, crossbites), CBCT may or may not be indicated on a case-by-case basis and should be considered as an alternative for cases that used to require MDCT examination, provided that the dose is lower and soft tissue imaging is not required. For the majority of orthodontic applications, post-treatment CBCTs are not likely indicated.

Apart from using the smallest possible FOV, one must reduce exposure parameters compared with those applied for an adult patient, taking the increase in dose and risk for children into account.

General misuses of CBCT

Cases in which the use of CBCT is inappropriate can be derived from Table 1, but will be briefly summarised. In general, routine use of CBCT without judicious evaluation of patient history, a clinical examination and previously acquired radiographs should not be done. Diagnoses or treatments that can be adequately performed through the use of 2D radiography or non-ionising modalities do not require CBCT. When a particular CBCT scanner does not allow for the adjustment of exposure parameters (e.g. FOV, mAs) suited for a particular patient, it should not be used; when possible, alternative CBCT models should be used instead. This implies that CBCT users, when purchasing a CBCT scanner, should be aware of the expected application range and choose a model with a fitting exposure range. Referring practitioners, when having a choice between several CBCT scanners, should be aware of the parameter ranges provided by each model and choose the most appropriate scanner for each patient rather than routinely opting for one scanner for reasons other than radiological protection.

FUTURE PROSPECTS

This paper provided a brief overview of radiation dose issues associated with the use of CBCT in dentistry. Through the use of different guidelines and position papers, the (mis)use of CBCT was illustrated for several dental applications.

As mentioned in each of the above-mentioned guidelines and position statements, periodic review is required in order to apply the most recent information on diagnostic efficacy and radiation dose and risk. In particular, as more comparative studies focusing on patient outcome become available, recommendations regarding the use of CBCT as a supplement or complement to 2D radiography may alter considerably. On the other hand, technological developments allowing for the reduction of patient dose (e.g. automatic exposure control, advanced reconstruction algorithms and improved detector technology) may increase overall confidence in the net benefit of CBCT. The use of health economics is warranted to evaluate all factors associated with the use of CBCT vs. alternative imaging modalities.

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